EVALUATION OF INTEGRATED SEISMIC HAZARDS AND GROUND FAILURE IN PULL-APART BASINS DURING 1999 KOCAELI EARTHQUAKE, TURKEY

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Program Element II: Research on Earthquake Occurrence and Effects

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INVESTIGATIONS UNDERTAKEN

The focus of this study is to investigate the ground failure mechanisms (i.e., tectonic subsidence, tsunami-induced drawdown and inundation, liquefaction, lateral spreading) that interacted within the Karamursel, Golcuk, and Lake Sapanca pull-apart basins, and caused severe damage during the 1999 Kocaeli earthquake in Turkey. The three goals of the study are:

(1) to determine the geometry of coastal failures within the pull-apart basins; (2) to determine the failure mechanisms and interaction of earthquake effects; and (3) to correlate geologic and geotechnical conditions with the mechanisms of failure.

This study is divided into four major tasks:

1. Collection of geologic and geotechnical data from the pull-apart basins
2. Selection of representative sites located in the pull-apart basins for detailed site investigation and analyses
3. Field investigation at the selected sites and laboratory testing of collected soil samples
4. Interpretation of data, and geotechnical and geologic analyses

Tasks 1 through 3 are planned for year 1 of this study and task 4 has been funded for year 2, as a continuation of this project. As of October 2001, representative test sites have been selected and the field site investigation is complete. Laboratory testing has been initiated and geotechnical and geologic analyses are planned for 2002.

RESULTS

Data Collection and Selection of Research Sites

Research sites from the Karamursel, Golcuk, and Lake Sapanca pull-apart basins were chosen after a review of previous observations and studies from the region. A table of pertinent information was developed to help choose the study sites. This table included information available for candidate sites, such as geologic conditions, ground subsidence, evidence of liquefaction, tsunami drawdown and inundation, ground motions, bathymetry, topography, and information from previous subsoil exploration (before and after the earthquake). Figure 1 contains a map of the Karamursel and Golcuk pull-apart basins, situated along the south shore of Izmit Bay. Figure 1 also shows a schematic of the Lake Sapanca pull-apart basin, which is located about 15 km east of Izmit Bay. Figure 1 includes data collected regarding geology, faulting, pull-apart basin geometry, locations of ground failure and subsidence, and locations of pertinent site data (e.g., borehole information, tsunami observations).

A significant observation from the collection of site information is the concentration of ground failure in recent delta fan deposits along the shores of Izmit Bay and Lake Sapanca. The delta deposits within the Golcuk pull-apart basin are indicated in Figure 1. Figure 1 shows that almost every delta deposit experienced liquefaction and/or subsidence. In fact, along the shores of Izmit Bay and Lake Sapanca, ground failure was observed at the mouth of almost every creek. These creeks are actively depositing loose delta sediments that are particularly susceptible to ground failure.

Based on the information collected, three research sites, namely Degirmendere, Seymen, and Esme, were selected for further site investigation and analyses.

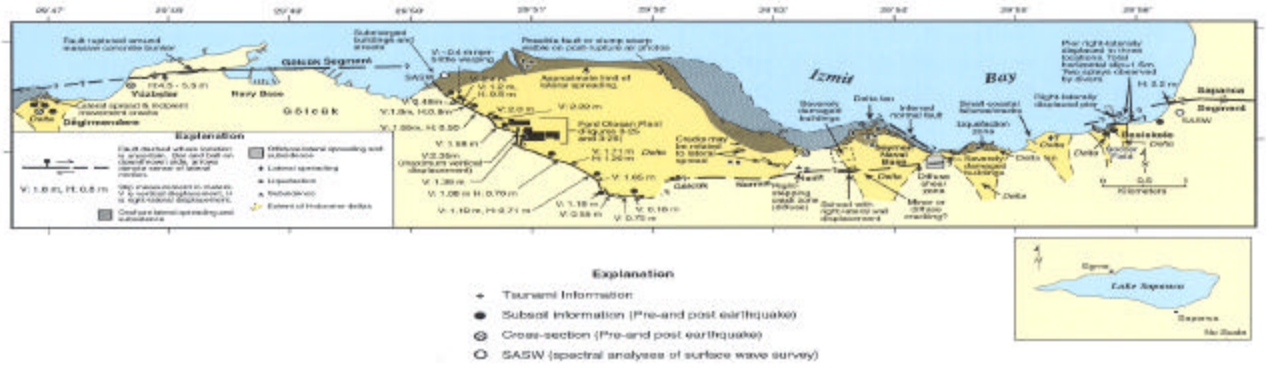

Figure 2. Relationships between coastal failure locations, Delta fans, and offshore faulting.

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Figure 1. Map of south shore of Izmit Bay and Lake Sapanca

Site Investigation

A site exploration and testing program was developed during Summer 2001. The field exploration was carried out in August 2001. Laboratory testing is currently underway. Details regarding the observed ground failure and the site exploration program at the three research sites are described below.

Degirmendere

A major coastal landslide occurred in a delta fan deposit in the city of Degirmendere, which is located on the southern coast of Izmit Bay and within the Karamursel pull-apart basin (Figure 1). A map of the landslide is shown in Figure 2. The area of the slide extended approximately 300 m along the coast and 75 m inland. A significant amount of land was submerged after the failure, creating a completely new coastline. Cracking extended inland, beyond the extent of the submerged area, but no evidence of liquefaction was observed.

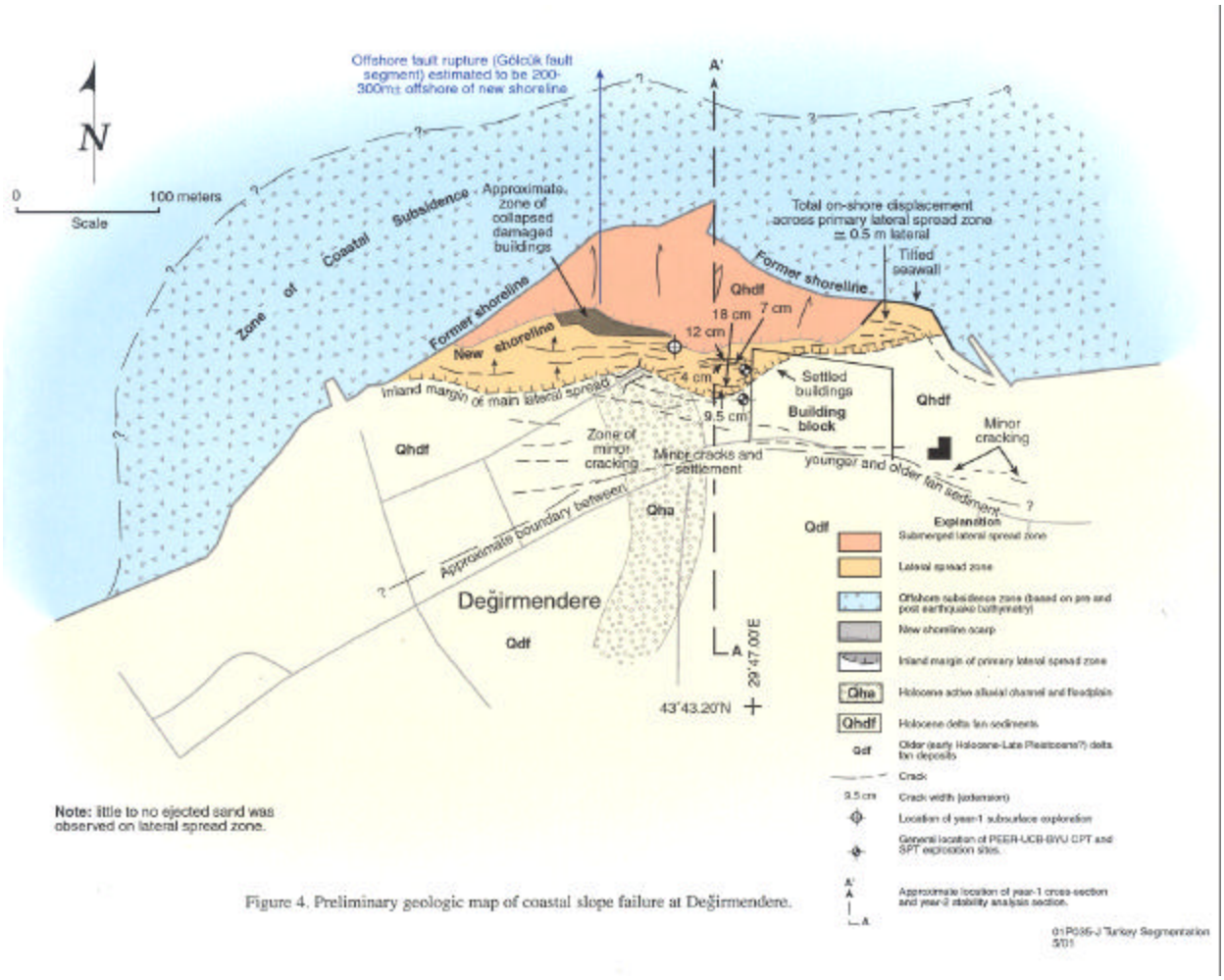

Figure 4. Preliminary geologic map of coastal slope failure at Değirmendere.

Figure 2. Coastal landslide and subsidence at Degirmendere

Boring logs from a site investigation performed close to the slide area after the earthquake were obtained from the city of Degirmendere, as well as results from bathymetric studies sponsored by the city after the earthquake. Further post-earthquake subsoil investigations were performed by Youd and Cetin (2000). These investigations were performed 20 to 60 m inland from the post-earthquake coastline and were located within a relatively older geologic unit than the slide. The maximum depth of the previous subsoil investigation was 20 m.

Because of the location and limited depth of previous borings, three additional borings were conducted as part of this study. Three rotary wash borings were performed and casing was used because of the ground conditions. The depth of the borings was approximately 30 m and about 20 standard penetration tests were performed in each borehole using a safety hammer. When appropriate, undisturbed samples were taken using Shelby tubes. Two of the borings were located about 0.5 m away from the post-earthquake shoreline, and about 60 m away from each other. These borings were located on each side of the creek that runs through the slide area and has deposited the delta sediments. The third boring was drilled about 25 m inland from the new shoreline and on the east side of the creek.

Seymen

Seymen is a small town located on the southern coast of Izmit Bay, within the Golcuk pull-apart basin, and about 10 km east of Degirmendere (Figure 1). A Holocene delta fan formed by a small creek has prograded into Izmit Bay at this location, and experienced ground failure, subsidence, and inundation during the earthquake. The area inundated included the MKE Scrap Yard area, which is relatively unpopulated. The creek that is responsible for the formation of the delta passes through the scrap yard. A concrete perimeter wall encircling the scrap yard was cracked and displaced by ground failure. Measurement of the cracks and cumulative displacement of this wall permit accurate determination of the extent and magnitude of ground movement in the Holocene delta deposits. During field testing, the location and magnitude of the wall cracks, and remaining ground cracks were recorded. These data were not previously collected, and represent significant new data for evaluation of ground failure. The ground cracking and lateral deformation extended approximately 200 m inland, and a major crack, about 1.5 m deep and 30 cm wide, was observed approximately 90 m from the shore. Wall cracks and displacement suggest that cumulative extensional movement was on the order of 1.5 to 1.6 m.

No previous borings have been performed at this site. For this study, two borings of 30 m depth and one boring of 5 m depth were performed. All of these borings were located west of both the MKE Scrap Yard and the creek, because it was not possible to drill east of the creek due to the presence of a Turkish Navy base. The same drilling and sampling procedures used at Degirmendere were used at the Seymen site. One borehole (30 m deep) was drilled immediately adjacent to the MKE Scrap Yard, about 100 m inland. This borehole was drilled inland because the soft sediments closer to the shore could not support the drill rig. The remaining two boreholes were drilled further west, directly adjacent to the shoreline. A photograph of this area after the earthquake, illustrating significant ground cracking within a tea garden, is shown in Figure 3. A very soft clay layer was detected in the top 5 m of the first borehole drilled next to the shoreline. Consequently, another borehole (5 m deep) was drilled adjacent to that borehole and field vane shear tests were performed to measure the peak and residual undrained shear strength of the soil.

Additionally, the water depth immediately offshore was measured using an ultrasonic device.

Water depth measurements were taken along several transects perpendicular to the shoreline, and the location of the measurements were recorded using GPS coordinates. Measurements were taken for a distance of approximately 250 m from the shoreline. The shoreline was also mapped using GPS coordinates.

Figure 3. Ground failure at tea garden near MKE Scrap Yard in Seymen

Esme

Esme is a town located on the north shore of Lake Sapanca (Figure 1), situated on alluvium deposited from the hills north of the lake. A large slide occurred along the coast in Esme, within delta sediments deposited by a creek. The area of the slide extended approximately 50 m along the coast and 35 m inland. The inland extension of ground cracks was about 150 m. Based on observations after the earthquake (EERI 2000), ground cracks showed pure extensional movement with no rotational component (Figure 4) and no evidence of liquefaction was observed. No subsoil information was available for this area.

Because of limited time, only a single borehole was drilled at this site. The borehole was drilled adjacent to the post-earthquake coastline, in the mouth of the source creek of the delta, which was dry at the time. Standard penetration tests and soil sampling were performed as described previously. Although the intention was to drill to 30 m depth, drilling was stopped at approximately 28 m depth due to high artesian pressure. It was judged to be unsafe to continue drilling because water from the boring was ejecting gravel-sized particles 3 to 4 m above the ground surface. This phenomenon occurred for approximately 15 minutes. It is interesting to note that residents informed us that "esme" means "do not dig" in Turkish, which may indicate

that artesian pressures have been observed previously in Esme.

In addition to soil exploration, water depths were also measured offshore. Measurements were taken along different transects perpendicular to the post-earthquake shoreline, for a distance of approximately 200 m.

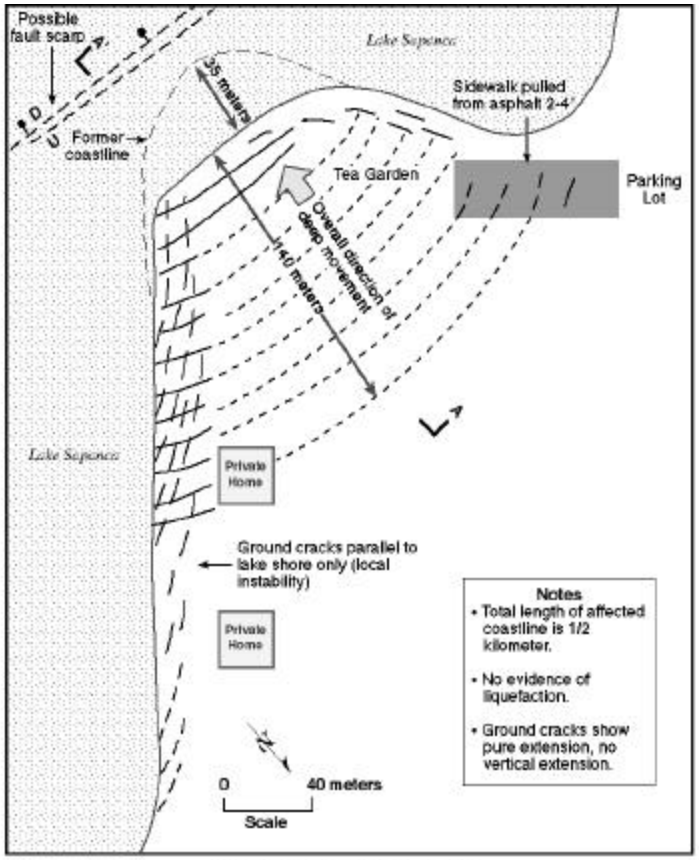

Figure 4. Mapped ground cracking at tea garden in Esme

Continuing Studies

Using the collected borehole data and water depth measurements, cross-sections are being developed for each site. An initial observation from the borehole data is that the subsoil at the sites is very heterogeneous, both laterally and vertically. The heterogeneity is most likely due to the depositional processes that occur in deltas. At Degirmendere, the near-shore borehole data indicate the mixture of alluvial and marine deposits over very short intervals of depth. For instance, it was common to encounter distinct layers of clean sand, clayey gravel, clay, and silty gravel in a single split spoon sample.

Presently, laboratory testing (e.g., sieve analysis, Atterberg limits) of disturbed samples is underway. Further site investigation using the cone penetration test (CPT) is being considered

because the CPT will be able to better identify the vertical layering within the delta fan deposits. The results from the drilling investigation, laboratory testing, and CPT testing will be used to perform detailed analyses (e.g., liquefaction analysis, slope stability analysis) for each site. The analyses will focus on identifying the mechanisms of ground failure at each site.

NON-TECHNICAL SUMMARY

Earthquake-induced ground failure and subsidence can cause considerable damage to coastal infrastructure. During the 1999 Kocaeli earthquake in Turkey, significant ground failure and damage were observed in coastal areas, and were particularly concentrated in step overs of the fault rupture. This study will focus on investigating the observed ground failure in Turkey. The investigations will correlate ground failure with the geologic and geotechnical conditions at the site and will evaluate the dominant mechanisms of ground failure. The results from this study can be applied to many sites in California, where critical facilities have been constructed in coastal areas near fault step overs.

REPORTS PUBLISHED

None at this time.

DATA AVAILABILITY

None at this time.

REFERENCES

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